Intel Embedded Processor Module Thermal Design Guide

Application Note

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Contents

1.0 **Introduction** 5

2.0 **Importance of Thermal Management** 5

3.0 **Component Power and Case Temperature Specifications** 5

4.0 **Thermal Parameters** 6

- 4.1 Ambient Temperature 6
- 4.2 Case Temperature 6
- 4.3 Measuring Case Temperature 7
- 4.4 Calculating Case-to-Ambient Thermal Resistance 7
- 4.5 Airflow Measurement 8

5.0 **TCP Package Thermal Characteristics** 8

6.0 **PC Board Thermal Enhancements** 8

- 6.1 Thermal Test Board Configuration 8

7.0 **Designing for Thermal Performance** 9

- 7.1 Extruded Heat Sink 10
- 7.2 Corrugated Heat Sink 12
- 7.3 Fan Heat Sink 14
- 7.4 Combination of Heat Pipe with a Cooling Device 14
- 7.5 Thermal Transfer Plate 15
- 7.6 Thermally Conductive Interface Materials Information 15
- 7.7 Heat Sink Handling Safety Precaution 16
- 7.8 Heat Sink Removal and Attachment 16
  - 7.8.1 Removing the Extruded Heat Sink 16
  - 7.8.2 Installing the Extruded Heat Sink 17
  - 7.8.3 Removing the Corrugated Heat Sink 17
  - 7.8.4 Installing the Corrugated Heat Sink 18
- 7.9 Thermal Characterization Data 18
  - 7.9.1 EMBMOD133 Airflow Required 19
  - 7.9.2 EMBMOD166 Airflow Required 20
  - 7.9.3 Module Thermal Characterization Data 20
  - 7.9.4 Individual Component Thermal Characterization Data 24
    - 7.9.4.1 EMBMOD133 24
    - 7.9.4.2 EMBMOD166 28

8.0 **Conclusion** 30

9.0 **Related Documents** 30

A **Vendor List** 31

Figures

1 Thermocouple Attachment for Measuring the Case Temperature 7
2 Cross-section of the Embedded Processor Module with TCP (Mounted) 9
3 CompactPCI Configuration Requirements 11
4 Extruded Heat Sink 11
5 Extruded Heat Sink Push Pin Drawing 12
6 Corrugated Heat Sink 13
7 Tuflok* Pin 13
8 Thermal Transfer Plate 15
9 Heat Sink Safety Label or Stamp 16
10 Heat Sink Push Pin 17
11 Embedded Processor Module and Board Orientation Options 19
12 Thermal Resistance vs. Airflow, 0° Rotation, EMBMOD133 21
13 Thermal Resistance vs. Airflow, 180° Rotation, EMBMOD133 21
14 Thermal Resistance vs. Airflow, 0° Rotation, EMBMOD166 22
15 Thermal Resistance vs. Airflow, 180° Rotation, EMBMOD166 23
16 Extruded Heat Sink: 133 MHz Pentium® Processor (TCP) Thermal Resistance vs. Airflow 24
17 Extruded Heat Sink: 82439HX System Controller (BGA) Thermal Resistance vs. Airflow 25
18 Extruded Heat Sink: SRAM (TQFP) Thermal Resistance vs. Airflow 25
19 Fan Heat Sink: 133 MHz Pentium® Processor (TCP) Thermal Resistance vs. Airflow 26
20 Fan Heat Sink: 82439HX System Controller (BGA) Thermal Resistance vs. Airflow 27
21 Fan Heat Sink: SRAM (TQFP) Thermal Resistance vs. Airflow 27
22 Corrugated Heat Sink: 166 MHz Pentium® Processor (TCP) Thermal Resistance vs. Airflow 28
23 Corrugated Heat Sink: 82439HX System Controller (BGA) Thermal Resistance vs. Airflow 29

Tables

1 Power Dissipation and Case Temperature Specifications for the Pentium® Processor and the Intel 82439HX System Controller (TXC) 6
2 Specified Case Temperature for Proper Operation 6
3 Tested Airflows and Rotation, EMBMOD133 22
4 Tested Airflows and Rotation, EMBMOD166 23
5 Extruded Heat Sink: 133 MHz Pentium® Processor (TCP) Thermal Resistance vs. Airflow 24
6 Extruded Heat Sink: 82439HX System Controller (BGA) Thermal Resistance vs. Airflow 24
7 Extruded Heat Sink: SRAM (TQFP) Thermal Resistance vs. Airflow 25
8 Fan Heat Sink: 133 MHz Pentium® Processor (TCP) Thermal Resistance vs. Airflow 26
9 Fan Heat Sink: 82439HX System Controller (BGA) Thermal Resistance vs. Airflow 26
10 Fan Heat Sink: SRAM (TQFP) Thermal Resistance vs. Airflow 27
11 Corrugated Heat Sink: 166 MHz Pentium® Processor (TCP) Thermal Resistance vs. Airflow 28
12 Corrugated Heat Sink: 82439HX System Controller (BGA) Thermal Resistance vs. Airflow 29
13 Related Documents 30
14 Vendor List 31

1.0 Introduction

The Embedded Processor Module is a high-performance subsystem for use in embedded, industrial and communication applications. Thermal management is important in these applications to achieve the necessary system performance.

This application note:

- Introduces the concepts and airflow calculations used when designing a thermal solution. Sample calculations are also provided.
- Provides thermal performance data for the Intel Embedded Processor Modules (EMBMOD133 and EMBMOD166)
- Recommends methods for meeting the thermal requirements imposed on systems

2.0 Importance of Thermal Management

The objective of thermal management is to ensure that the temperature of all components is maintained within specified functional limits. The functional temperature limit is the range within which the electrical circuits can be expected to meet their specified performance requirements. Operation outside the functional limit can degrade system performance and cause reliability issues.

The case temperature is the surface temperature of the package at its hottest point. Temperatures exceeding the case temperature limit can cause physical destruction or may result in irreversible changes in operating characteristics.

3.0 Component Power and Case Temperature Specifications

The power dissipation and case temperature specifications are shown in Table 1 for the 133 MHz and 166 MHz Pentium® Processors in the Tape Carrier Package (TCP) and the Intel 82439HX System Controller (TXC) in a Ball Grid Array (BGA) package. The designer should collect similar data from the specific vendor for the 32Kx32 PBSRAM, Voltage Regulator, Clock Driver, 14.318 MHz Crystal, and 32Kx8 SRAM.

Table 1. Power Dissipation and Case Temperature Specifications for the Pentium® Processor and the Intel 82439HX System Controller (TXC)

IC Component	Package Type	Total Pins	Package Size (Max)	Typical Power (W)	Max Power (W)	Max Case Temp (°C)
Pentium® Processor (133 MHz)[1]	TCP	320	24 mm x 24 mm	3.5	7.9	95
Pentium® Processor (166 MHz)[2]	TCP	320	24 mm x 24 mm	5.5	8.9	95
82439HX System Controller (TXC)	BGA	324	27.2 mm x 27.2 mm	1.0	1.2	85

NOTES:
1. For more information, refer to the *Pentium® Processor with Voltage Reduction Technology* datasheet (order number 252557).
2. For more information, refer to the *Mobile Pentium® Processor with MMX™ Technology* datasheet (order number 243292).

4.0 Thermal Parameters

Component power dissipation raises the temperature of the component relative to the temperature of a reference point. How much the temperature rises depends on the net thermal resistance between the component's package and the reference point. Thermal resistance is the key factor in determining the power handling capability of any electronic package and the design of a thermal solution.

4.1 Ambient Temperature

Ambient temperature (T_A) is the temperature of the undistributed air surrounding the package. Ambient temperature is usually measured at a specified distance from the module. In a system environment, ambient temperature is the temperature of the air upstream to the module and in its close vicinity. In a typical laboratory test environment, ambient temperature is measured 12 inches (or as close to 12 inches as possible) upstream from the module to represent the ambient temperature with air flowing past the system. When natural convection is used in a system, the ambient temperature is measured directly underneath the board module.

4.2 Case Temperature

Table 2 lists the case temperature (T_C) that is specified for proper operation of the listed device. All other components specify a maximum operating temperature of 70° C.

Table 2. Specified Case Temperature for Proper Operation

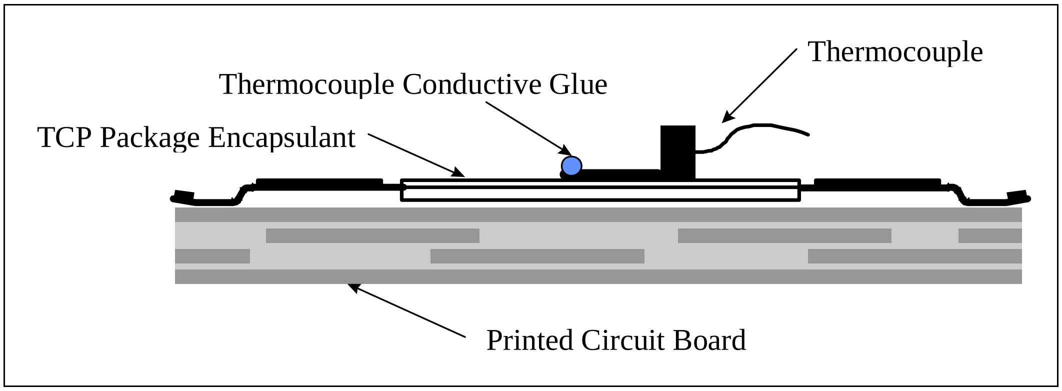
Device	Package	T_C
Pentium® processor	Tape Carrier Package (TCP)	0° C and 95° C
Intel 82439HX System Controller (TXC)	Ball Grid Array (BGA)	0° C and 85° C
SRAMs	Thin Quad Flat Pack (TQFP)	0° C and 95° C

4.3 Measuring Case Temperature

To verify that the proper T_C is maintained for the Pentium processor, it should be measured at the center of the top surface of the package. To minimize any measurement errors, the following techniques and materials are recommended:

- Use 36 AWG or finer diameter K, T, or J type thermocouples. Intel's laboratory testing was performed using a thermocouple offered by Omega Engineering, Inc. (part number: 5TC-TTK-36-36).
- Attach the thermocouple bead or junction to the center and top surface of the package using a cement or glue that is highly thermally conductive. Intel's laboratory testing was performed using Omega Bond* (Part number: OB-101).
- Attach the thermocouple at a 0° angle on the center of the top surface of the package as shown in Figure 1.

Figure 1. Thermocouple Attachment for Measuring the Case Temperature



4.4 Calculating Case-to-Ambient Thermal Resistance

For the Pentium processor with voltage reduction technology, an ambient temperature is not specified directly. The only requirement is that the case temperature is met. The case-to-ambient thermal resistance can be calculated from the following equation:

Equation 1. $$\theta_{CA} = (T_C - T_A)/P$$

where:

θ_{CA} = Case-to-Ambient thermal resistance (°C/W)
T_A = ambient temperature (°C)
T_C = case temperature (°C)
P = device power dissipation (Watts)

For example, assuming the case temperature is 95° C, the ambient temperature is 50° C, and the typical power dissipated by the 133 MHz Pentium processor is 3.5 W, the case-to-ambient thermal resistance (θ_{CA}) is 12.9° C/W.

Knowing the θ_{CA} value allows the system designer to determine the estimated airflow required to keep the TCP case temperature at 95° C and helps the designer determine the best way to orient the board to obtain the minimum airflow requirement.

4.5 Airflow Measurement

The airflow or air velocity flowing across the components can be measured using a portable hot wire anemometer. The meter contains two temperature sensing elements. One element is used to track the air stream temperature and the second element is heated by an electrical current to maintain a constant temperature above the air stream temperature. As the air stream takes heat energy away from the heated element, more current is required to maintain the temperature differential. The required electrical current is proportional to the air mass velocity which is displayed on the meter. This meter is available from Kurz Instruments; refer to the vendor list in Appendix A for contact information.

5.0 TCP Package Thermal Characteristics

The primary heat transfer path from the die of the TCP is through the back side of the die and into the printed circuit (PC) board. There are two thermal paths traveling from the PC board to the ambient air. One is the spread of heat within the board and the dissipation of heat by the board to the ambient air. The other is the transfer of heat through the board to the opposite side where thermal enhancements (heat sinks, fans, pipes, etc.) are attached.

6.0 PC Board Thermal Enhancements

Copper planes, thermal pads, and vias are design options that can improve heat transfer from the PC board to the ambient air. It should be noted that although thicker copper planes reduce the θ_{CA} of a system without any thermal enhancements, thicker planes have less effect on the θ_{CA} of a system with thermal enhancements. Placing vias under the die reduces the θ_{CA} of a system with and without thermal enhancements.

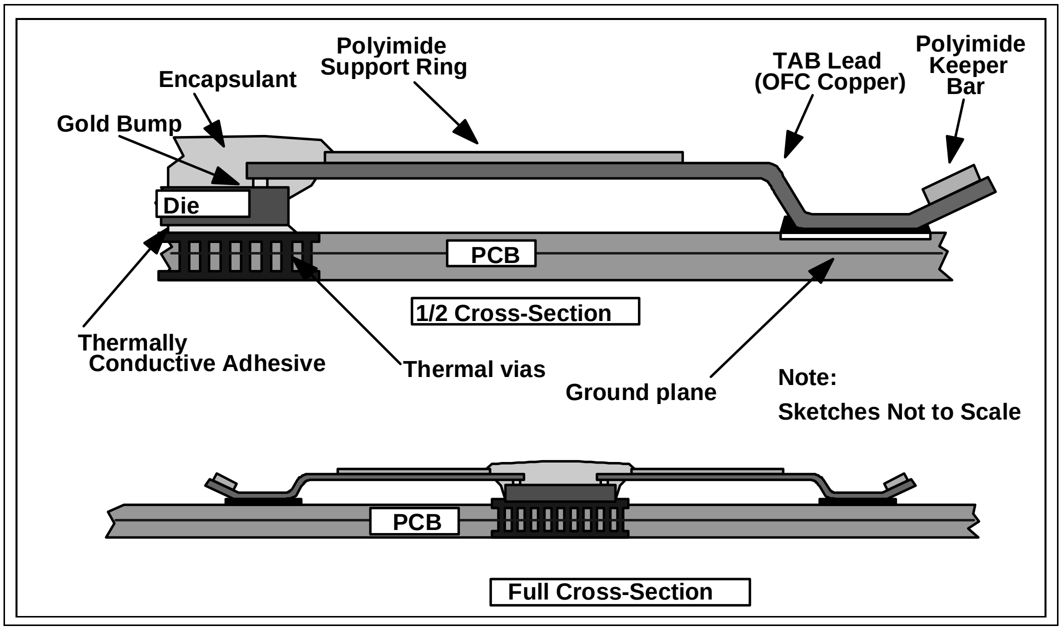
6.1 Thermal Test Board Configuration

The thermal measurements for the modules were taken with a Pentium processor in the TCP package soldered to a 4" x 3" test board outline.

The EMBMOD133 six-layer board contains 10.0 mil drill holes on 50 mil pitch vias (underneath the die) in the die attach pad; the vias are connected to a 1 oz. copper plane. A 13 X 13 array of thermal vias conducts the heat generated by the Pentium processor to the top side of the board where a heat sink is attached to assist in heat dissipation. The EMBMOD166 six-layer board contains 297 thermal vias that are on 13 mil drill holes, 25 mil pitch, and are connected to a 2 oz. copper plane. The vias in the die attach pad are connected without thermal paths to the ground plane(s). The die is attached to the die attach pad using a thermally and electrically conductive adhesive as shown in Figure 2.

The test board was designed to optimize the heat spreading into the board and the heat transfer through to the opposite side of the board. Thermal die was used to represent each of the components with a power of 1W or greater. The test board included thermal die for the Pentium processor in a TCP package, the Intel 82439HX System Controller (TXC) in a BGA package, and the 32Kx32 PBSRAM in a TQFP package.

Figure 2. Cross-section of the Embedded Processor Module with TCP (Mounted)



7.0 Designing for Thermal Performance

This section describes how to apply the thermal characteristics to a system thermal design. The goal of a thermal solution is to maintain the case temperatures of all the IC components on the board module. The main factors that determine the type of thermal solution to use are:

- Performance target
- Cost
- Amount and direction of airflow
- Available pressure drop
- Heat sink geometry
- Heat sink attachment to board

Three thermal solutions are available for the module that satisfy many broad-market requirements. Intel only offers the Embedded Processor Module with a heat sink.

The three available solutions are a passive heat sink, an active fan heat sink, and a liquid-cooled heat pipe and cooling device combination. A passive heat sink system is the simplest and most cost-effective solution when the design can include ample airflow. The active fan heat sink solution should be used in designs without forced airflow that are operating at a typical ambient temperature of 50° C. For designs operating at high ambient temperatures and restricted to only natural convection, a heat pipe with a cooling device may be the only solution.

The CompactPCI specification was used to determine the overall form factor of the Embedded Processor Module and the height allowed for the thermal solution. For a copy of the CompactPCI specification, contact Rogers Communication at the address listed in Appendix A.

The design optimization of a thermal solution is not trivial. The designer must consider the following parameters when designing a high-performance, low-cost thermal solution:

- Surrounding ICs
- Maximum power of all components
- Ambient and case temperatures
- Module orientation
- Direction of airflow
- Heat source area
- Top/bottom heat dissipation of component
- Manufacturability
- Tooling for testing and manufacturing
- Fin profile (round, oval, square, convoluted, folded or corrugated)
- Unidirectional vs. omnidirectional fins
- Fin geometry (height, thickness, and distance between fins)
- Base plate geometry (thickness and area)
- Material (aluminum, copper, and alloy)
- Heat sink attachment mechanism
- Heat sink attachment material (grease, dry-film, thermal tape)
- Heat sink attachment thickness and coverage area
- Heat sink surface treatment (e.g., anodizing)
- Safety/caution labels
- UL recognition (or equivalent)
- Available pressure drop

Appendix A lists vendors for heat sink fans, heatpipes, pins, springs, heat sink attach/interface materials, and measurement equipment. The current PCB manufacturer and the address for requests for copies of the CompactPCI Specification are also listed.

7.1 Extruded Heat Sink

The EMBMOD133 uses an extruded, unidirectional heat sink that meets the CompactPCI form-factor requirement with a height of 0.275 inches (6.98 mm), and can dissipate the Pentium processor's maximum power of 7.9 W. This cooling solution was demonstrated to meet the 95° C case temperature and a 50° C ambient temperature. The amount of airflow required can change depending on where the system fan is located. The module's orientation in the system (Figure 11) determines how much airflow is needed.

All of the conditions for a particular application must be taken into consideration to determine if this particular heat sink is sufficient or if a new heat sink design is required. This design was targeted to meet the CompactPCI component height requirement as shown in Figure 3. If there is no need to meet this height requirement, a taller heat sink can be designed. The extruded heat sink is shown in Figure 4 and the push pin used to attach the heat sink to the module is shown in Figure 5.

Figure 3. CompactPCI Configuration Requirements

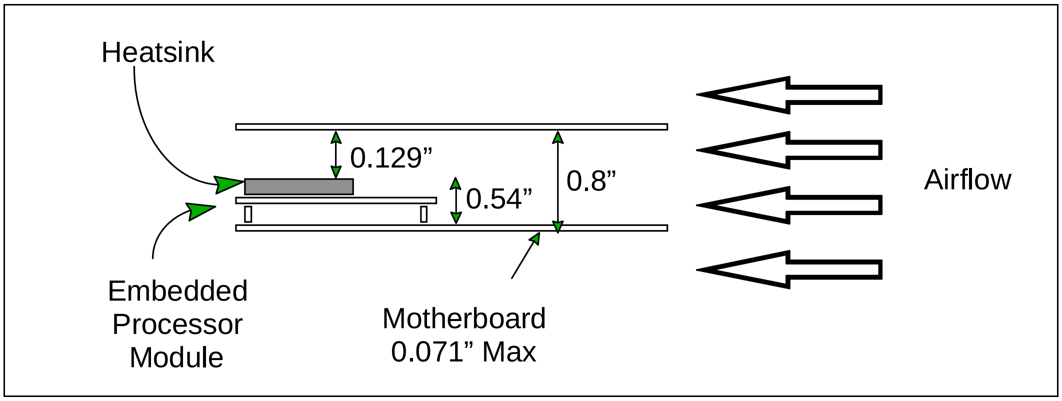


Figure 4. Extruded Heat Sink

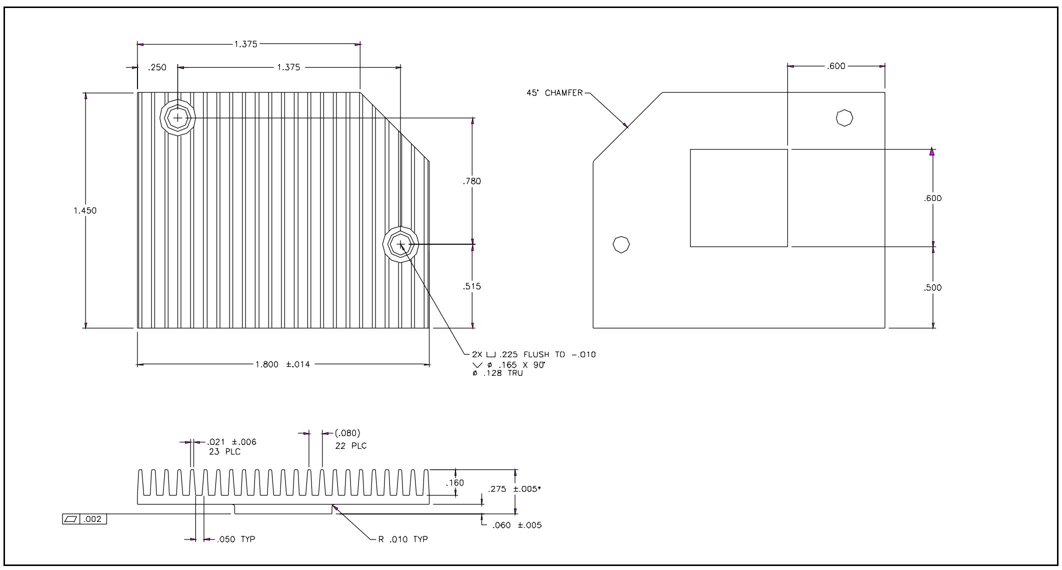
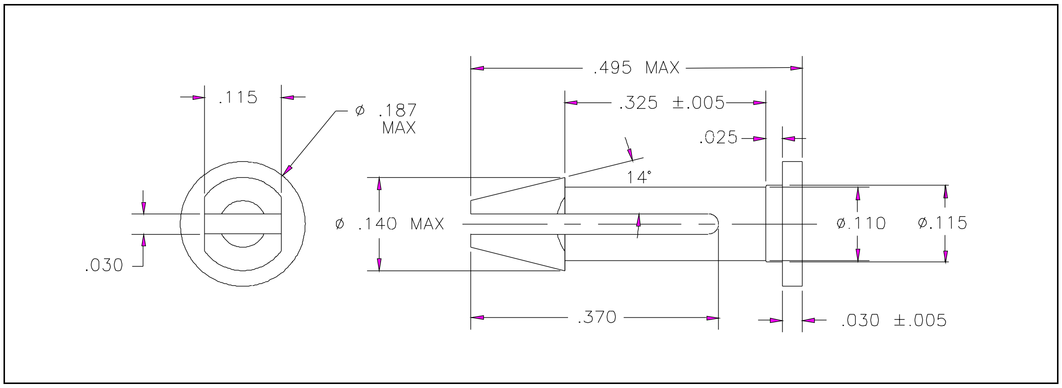


Figure 5. Extruded Heat Sink Push Pin Drawing



7.2 Corrugated Heat Sink

Corrugated heat sinks are made of aluminum and may provide superior performance over the extruded heat sink. The heat sink fins are a thin layer of aluminum bent in an “S” shape and brazed onto the base plate of the heat sink. The fins are perforated in random locations to provide better cooling performance. The corrugated heat sink is shown in Figure 6 and the Tuflok* pin used to attach the heat sink to the module is shown in Figure 7.

The EMBMOD166 uses a corrugated heat sink that meets the CompactPCI height requirement (see Figure 3). The height of the heat sink is 0.275” (6.98 mm) and can dissipate the Pentium processor maximum power of 8.9 W at 50° C ambient temperature and 95° C case temperature.

Figure 6. Corrugated Heat Sink

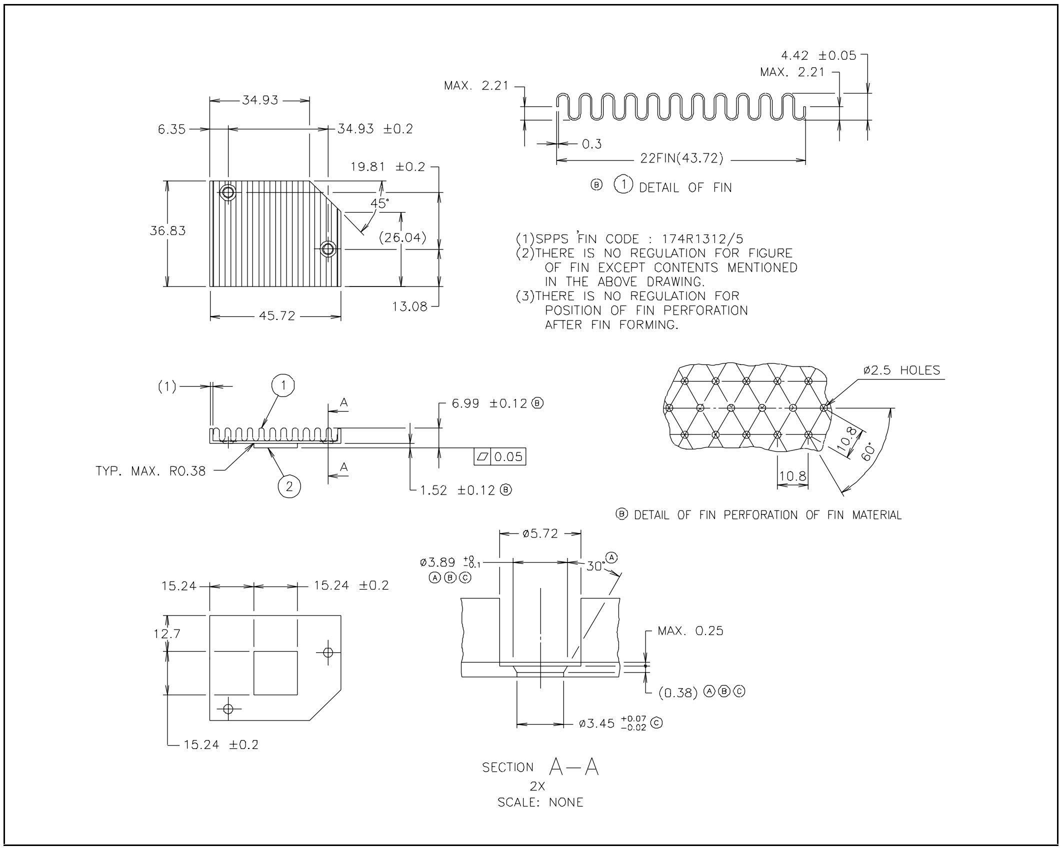
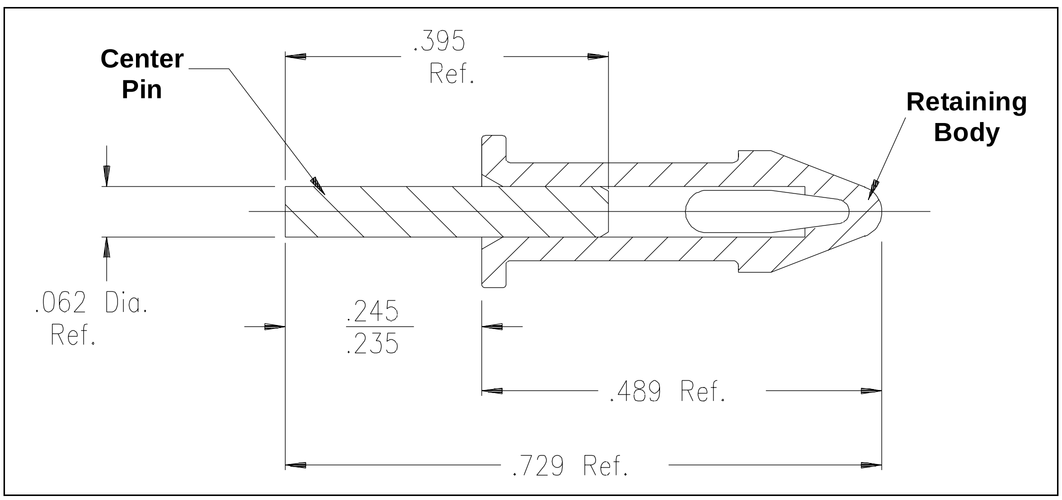


Figure 7. Tuflok* Pin



7.3 Fan Heat Sink

Fans are often needed to move the air inside a system chassis. The airflow rate is usually directly related to the acoustic noise level of the fan and system. Maximum acceptable noise levels may limit the fan output or the number of fans selected for a system. A fan may be attached to the chassis, and an additional fan may be placed at the top of a heat sink to produce direct air impingement on the heat sink for efficient heat removal.

For the module, a low profile fan heatsink was designed with a height of 8.9 mm. The height of this fan heatsink solution exceeds the CompactPCI height requirement of 7 mm or less. This solution was designed to cool the Pentium processor to meet an ambient temperature of 50° C and a case temperature of 95° C, and to dissipate a maximum power of 7.9 W with no other airflow required by the system. The thermal characterization data for this design is provided in Section 7.8.

The fan heat sink can be made with two alarm sensors:

- A sensor that outputs a pulse when the fan is in an abnormal state.
- A thermal sensor with a built-in thermistor that monitors the surface temperature of the processor.

A customer may request one of these options from the fan vendor. The customer should also consult the fan vendor on how to provide power to the fan on the system board. The module is not offered with a fan heatsink, but the fan heatsink is available (see the vendor list in Appendix A).

7.4 Combination of Heat Pipe with a Cooling Device

Customers limited to system designs that require an ambient temperature of 60–70° C and can only provide airflow by natural convection (less than 200 LFM), may have to design a heat pipe with a cooling device. The purpose of a heat pipe is to spread the heat from a concentrated source to a heat sink for dissipation to a coolant such as air or water. Heat enters the heat pipe at its evaporator where it causes the fluid to vaporize. The vapor travels from the evaporator to the condenser through the adiabatic section (long section of the pipe). The vaporized fluid creates a pressure gradient that forces the vapor towards the condenser or the cool area. The condensed fluid is drawn back into the pores of the wick for return to the evaporator. The wick serves as a pump using capillary pressure to return the fluid from the condenser to the evaporator. The wick also acts as an extended surface to allow higher heat fluxes.

The typical configuration includes a heating plate/block on top of the TCP package. The heating plate/block is connected to a heat pipe which is connected to a cooling plate/block, heat sink or fan heat sink. The most common heat pipe is made of copper and filled with water. The performance of the heat pipe increases as the length of the heat pipe decreases and the diameter of the heat pipe increases. A heat pipe can be bent or formed before or after fabrication to meet the system space requirements. Each bend lowers the performance of the heat pipe. Heat pipes can have a long life of 100,000 hours or more, depending on the design. Contact the vendor for reliability data.

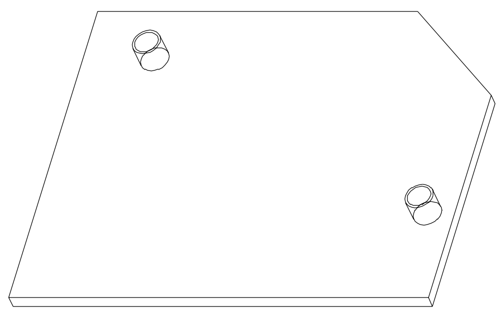
The heat pipe thermal resistance is the sum of the conduction through the wall of the pipe, conduction through the wick, evaporation temperature difference, vapor pressure drop, condensation temperature difference (ΔT), conduction through the wick, and conduction through the heat pipe wall on the opposite side of the pipe. The predominant thermal resistances are the evaporation (ΔT) and the vapor pressure drop.

A heat pipe solution is a unique, customer specific solution. The customer must provide the system environment, application and thermal requirements to the heat pipe vendors in order to generate an optimal design. Refer to Appendix A for a list of heat pipe vendors.

7.5 Thermal Transfer Plate

A thermal transfer plate (TTP) is available to attach a fan, heatsink or heatpipe solution to cool the processor. The plate is attached to the board with standard screws through the backside of the board. The screw is flush with the TTP. A non-conductive, nylon washer is placed between the board backside and the head of the screw to avoid shorting nearby traces or vias. Refer to Appendix A for a list of thermal transfer plate vendors.

Figure 8. Thermal Transfer Plate



7.6 Thermally Conductive Interface Materials Information

The current heat sink attachment interface material is a thermally and electrically conductive grease. Thermal grease provides an effective interface between the heat sink and the processor package. Thermal grease typically provides the lowest thermal resistance of the available alternatives.

Other thermally conductive materials such as copper heat spreaders, film, tape, adhesives or gap fillers may be used to enhance the thermal characteristics of components that do not have a heat sink solution, such as the 82439HX System Controller, SRAMs, and the side of the Pentium processor package opposite the heat sink.

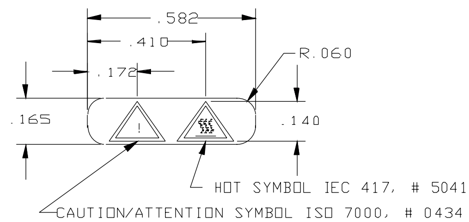
A copper tape heat spreader placed on top of the exposed components yielded a five degree or better drop for the processor and a 10 degree or better drop for the system controller and cache components. Two copper spreaders may be placed in a “criss-cross” fashion to further improve the thermal performance of the processor. Refer to Appendix A for interface material vendors.

7.7 Heat Sink Handling Safety Precaution

The heat sink temperature should not rise above 95° C at worst-case power conditions. Intel requires a safety label or stamp to be placed on the heat sink as a warning to indicate that this part is hot. The safety label uses the caution/attention symbols (ISO 7000, # 0434 and IEC 417, # 5041) to provide this warning, as shown in Figure 9.

Caution: Allow the heat sink to cool to room temperature before removing the heat sink from the module.

Figure 9. Heat Sink Safety Label or Stamp



7.8 Heat Sink Removal and Attachment

Intel does *not* recommend removing the heat sink from the Embedded Processor Module. But if you must remove the heat sink for a custom thermal solution, care must be taken not to damage the module or any components on the module. Custom thermal solutions must also ensure that maximum case temperatures for all components on the Embedded Processor Module are not exceeded.

Warning: Damage to the board or components voids the warranty of the module.

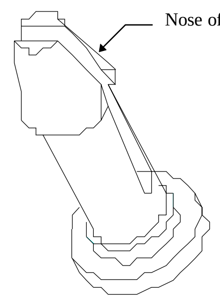
7.8.1 Removing the Extruded Heat Sink

The following procedure *must* be followed when removing the extruded heat sink from the EMBMOD133:

Caution: Allow the heat sink to cool to room temperature before removing the heat sink from the module.

1. Wear a grounding strap at all times when handling the modules to protect against electrostatic discharge.
2. Use needle-nose pliers to gently squeeze the nose of each push pin together and push the pins through the module.

Figure 10. Heat Sink Push Pin



7.8.2 Installing the Extruded Heat Sink

The following procedure *must* be followed when installing the heat sink on the EMBMOD133:

Caution: Allow the heat sink to cool to room temperature before removing the heat sink from the module.

1. Remove any existing thermally conductive grease with a clean cloth.
2. Add approximately 1/8 gram of thermally conductive grease evenly onto the pedestal of the heat sink.
3. Align the heat sink holes with the plated holes on the module.
4. Press push pins through the holes with approximately 6 lb. force until the nose of the pin latches onto the module.

Note: See Appendix A for a list of vendors of thermally conductive grease.

7.8.3 Removing the Corrugated Heat Sink

The following procedure *must* be followed when removing the corrugated heat sink from the EMBMOD166:

Caution: Allow the heat sink to cool to room temperature before removing the heat sink from the module.

1. Wear a grounding strap at all times when handling the modules to protect against electrostatic discharge.
2. Cut off the bottom of the Tuflok* pin and remove the pin.

Note: The pins can only be used once. New Tuflok pins will have to be installed to re-attach the heat sink. New springs may also be required. See Appendix A for pin and spring supplier contact information.

7.8.4 Installing the Corrugated Heat Sink

The following procedure *must* be followed when installing the heat sink on the EMBMOD166:

Caution: The corrugated heat sink fans have perforated holes in random locations for better thermal performance. These holes may be located at the edges of the heatsink and must be avoided during handling.

1. Remove any existing thermally conductive grease with a clean cloth.
2. Add approximately 1/8 gram of thermally conductive grease evenly onto the pedestal of the heat sink.
3. Align the heat sink holes with the plated holes on the module.
4. Press the Tuflok retaining body (see Figure 7) through the PCB holes with approximately 25-27 lb. of force until the nose or bottom end of the pin latches onto the module. Insert the center pin with about 8-10 lb. of force.

7.9 Thermal Characterization Data

The system designer must take into account the requirements of every component on the module when determining the airflow required for the Embedded Processor Module. The airflow required depends on the ambient temperature, design power of each device, the placement of the module in the system chassis, and the direction in which the system fan blows air across the module. It is important for the system designer to ensure that all case temperature requirements are met for each component on the module. This section describes how to estimate the airflow required to keep the module functioning correctly. Refer to “Thermal Parameters” on page 6 for a description of the airflow and temperature measurement technique.

The case-to-ambient thermal resistance (θ_{CA}) was collected for these module components:

- Pentium processor in a TCP package
- Intel 82439HX System Controller (TXC) in a BGA package
- 32Kx32 PB SRAM in a TQFP package

The other components were not considered in the characterization because of their low operating power conditions. The θ_{CA} values were gathered for the extruded heat sink, corrugated heat sink, and fan heat sink. All measurements were taken in an “open air” wind tunnel environment in which there was no enclosure around the module.

For the heat sink characterization, the module was placed in a wind tunnel in two different orientations, a 0° rotation and a 180° rotation as shown in Figure 11. The system designer can choose the orientation of the module that provides the minimum airflow requirement of the system environment.

Figure 11. Embedded Processor Module and Board Orientation Options

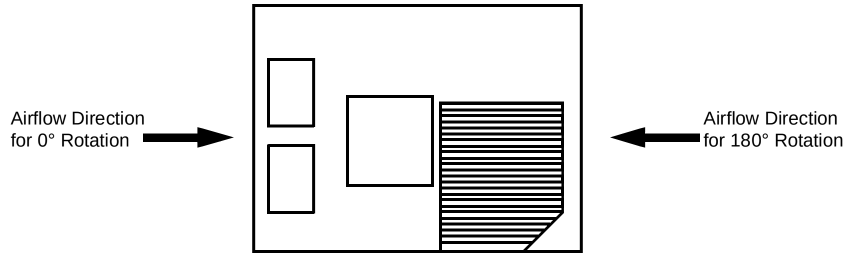


Figure 11 shows the airflow direction used in the following description. Figures 12 through 15, and Tables 3 and 4 show the relationship between the thermal resistance (θ_{CA}) and the airflow (in linear feet per minute) for the EMBMOD133 and EMBMOD166 modules. Two curves are shown for each module:

0° rotation: This curve represents the thermal resistance vs. airflow when the module is in the 0° rotation. In the 0° rotation the airflow passes across the SRAMs, the 82439HX System Controller, and the Pentium processor in that order. The thermal characterization results show that the Pentium processor (TCP) thermal requirements determine the airflow required with the module in the 0° rotation. The TCP case temperature of 95° C and the operating power range of the Pentium processor should be used to determine the thermal resistance and airflow in the 0° rotation.

180° rotation: This curve represents the thermal resistance vs. airflow when the module is in the 180° rotation. In the 180° rotation the airflow passes across the Pentium processor, the 82439HX System Controller, and the SRAMs in that order. The 82439HX System Controller thermal requirements determine the airflow required with the module in the 180° rotation of the board. The BGA case temperature of 85° C and operating power range of the 82439HX System Controller should be used to determine the thermal resistance and airflow requirement in the 180° rotation.

7.9.1 EMBMOD133 Airflow Required

The system designer can determine the approximate airflow required by calculating the θ_{CA} (refer to Section 4.4 on page 7) and charting this value onto the graphs in Figure 12 and Figure 13. For example, to determine the airflow required for typical power consumption when the extruded heat sink exists on the module:

T_C (TCP) = 95° C; T_C (BGA) = 85° C
T_A = 50° C T_A = 50° C
P (TCP) = 3.5 W; P (BGA) = 1.0 W
θ_{CA} (TCP, 0° Rotation) = 12.9° C/W ➟ Requires 100 LFM
θ_{CA} (BGA, 180° Rotation) = 35.0° C/W ➟ Requires 325 LFM

Figure 12 and Figure 13 indicate that an airflow of 325 LFM is required in the 180° rotation of the module and less than 100 LFM in the 0° rotation for typical power conditions. Therefore, it is recommended that the board be oriented in the 0° rotation.

For maximum power consumption when the extruded heat sink exists on the module:

T_C (TCP) = 95° C; T_C (BGA) = 85° C
T_A = 50° C T_A = 50° C
P (TCP) = 7.9 W; P (BGA) = 1.2 W
θ_{CA} (TCP, 0° Rotation) = 5.7° C/W ➟ Requires 550 LFM
θ_{CA} (BGA, 180° Rotation) = 29.1° C/W ➟ Requires 550 LFM

Use Equation 1 on page 7 to calculate θ_{CA} and then use the graphs of Figure 12 and Figure 13 to find the corresponding airflow required. Both graphs indicate that 550 LFM airflow is needed to meet maximum power conditions for both board rotations (0° and 180° rotation).

7.9.2 EMBMOD166 Airflow Required

Below is an example of determining the airflow required during typical power consumption for the EMBMOD166 with a corrugated heat sink:

T_C (TCP) = 95° C; T_C (BGA) = 85° C
T_A = 50° C
P_{TCP} = 5.5 W, P_{BGA} = 1.0 W
θ_{CA} (TCP, 0° rotation) = 8.2 °C/W ➟ Requires 300 LFM
θ_{CA} (BGA, 180° rotation) = 35.0 °C/W ➟ Requires 375 LFM

Figure 14 and Figure 15 indicate that this example would require about 300 LFM in the 0° rotation, and about 375 LFM in the 180° rotation.

The next example shows the same calculation for maximum power consumption:

T_C (TCP) = 95° C; T_C (BGA) = 85° C
T_A = 50° C
P_{TCP} = 8.9 W, P_{BGA} = 1.2 W
θ_{CA} (TCP, 0° rotation) = 5.0 °C/W ➟ Requires 800 LFM
θ_{CA} (BGA, 180° rotation) = 29.1 °C/W ➟ Requires 600 LFM

Figure 14 and Figure 15 indicate that this example would require about 800 LFM in the 0° rotation, and about 600 LFM in the 180° rotation.

7.9.3 Module Thermal Characterization Data

Figures 12 and 13 and Table 3 represent the thermal characterization data for the EMBMOD133 module. Figures 14 and 15 and Table 4 represent the thermal characterization data for the EMBMOD166 module.

Figure 12. Thermal Resistance vs. Airflow, 0° Rotation, EMBMOD133

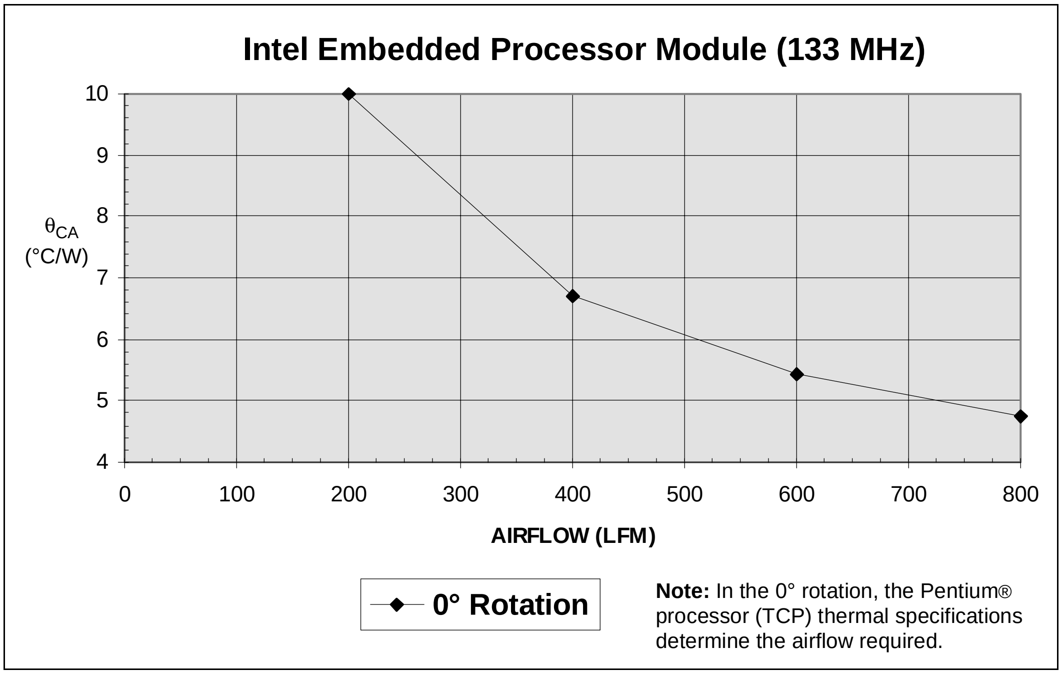


Figure 13. Thermal Resistance vs. Airflow, 180° Rotation, EMBMOD133

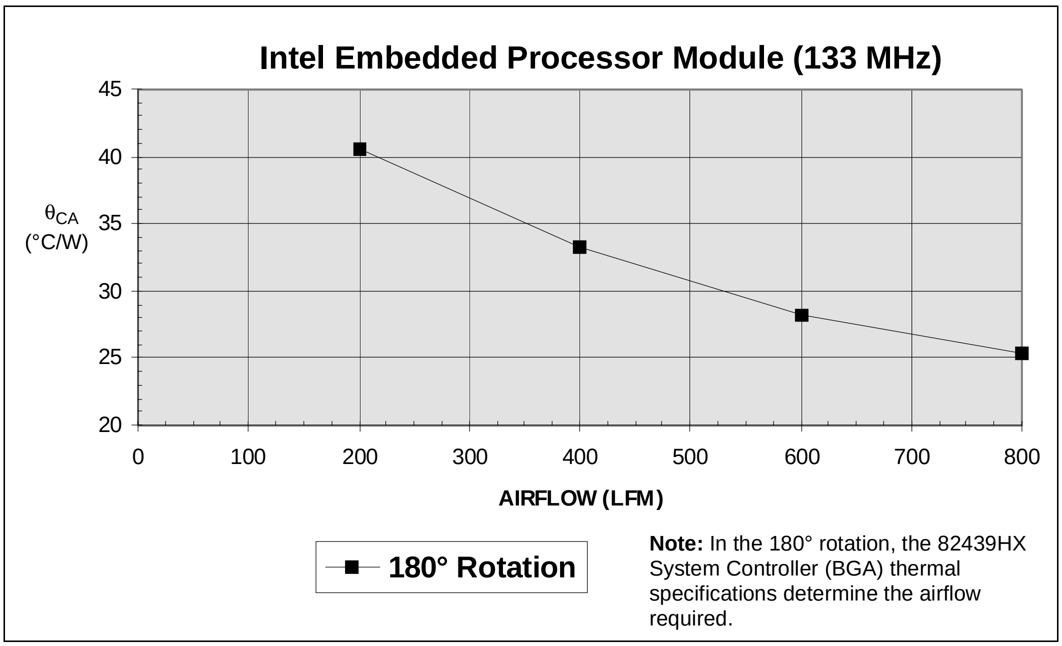
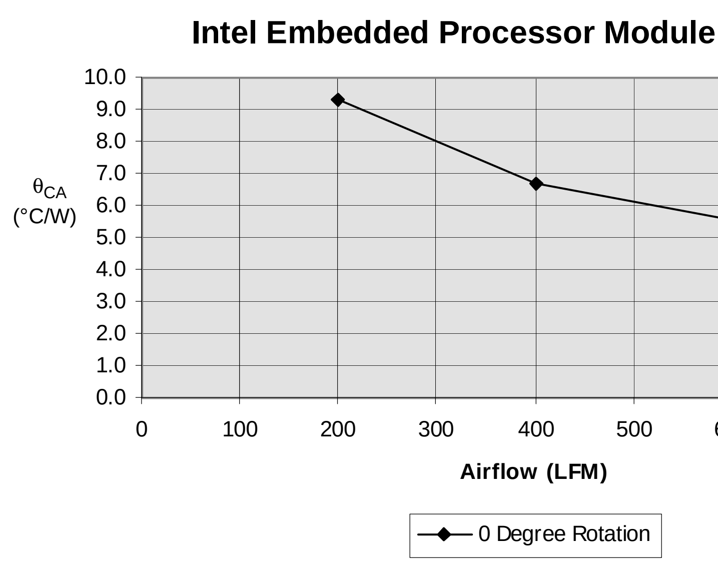


Table 3. Tested Airflows and Rotation, EMBMOD133

Airflow	θ_{CA} (0° Rotation)	θ_{CA} (180° Rotation)
800	4.8	25.4
600	5.4	28.2
400	6.7	33.2
200	10.0	40.5

Figure 14. Thermal Resistance vs. Airflow, 0° Rotation, EMBMOD166



Note: In the 0° rotation, the Pentium® processor (TCP) thermal specifications determine the airflow required.

Figure 15. Thermal Resistance vs. Airflow, 180° Rotation, EMBMOD166

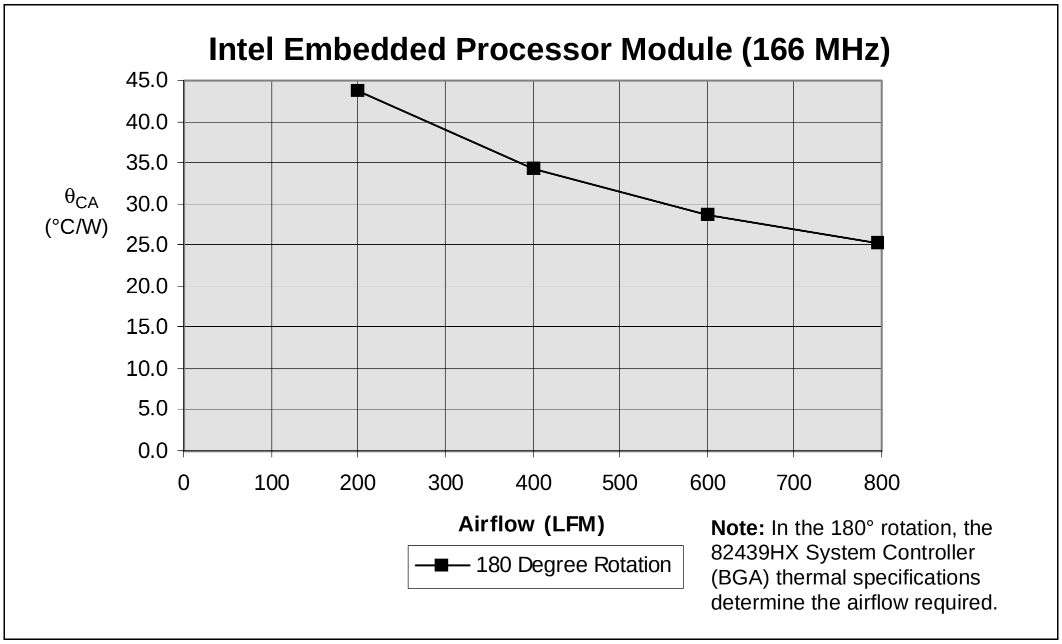


Table 4. Tested Airflows and Rotation, EMBMOD166

Airflow	θ_{CA} (0° Rotation)	θ_{CA} (180° Rotation)
800	5.1	25.4
600	5.6	28.8
400	6.7	34.2
200	9.3	43.8

7.9.4 Individual Component Thermal Characterization Data

The data in this section is provided to help the designer understand the characteristics of the individual components used on the modules.

7.9.4.1 EMBMOD133

Figures 16, 17 and 18 and Tables 5, 6 and 7 represent the data for the extruded heat sink on the EMBMOD133 module. Figures 19, 20 and 21 and Tables 8, 9 and 10 represent data for the fan heat sink on the EMBMOD133 module.

Table 5. Extruded Heat Sink: 133 MHz Pentium® Processor (TCP) Thermal Resistance vs. Airflow

Airflow (LFM)	0° Rotation θ_{CA} (°C/W)	180° Rotation θ_{CA} (°C/W)
800	4.8	4.6
600	5.4	5.1
400	6.7	5.9
200	10.0	7.4

Figure 16. Extruded Heat Sink: 133 MHz Pentium® Processor (TCP) Thermal Resistance vs. Airflow

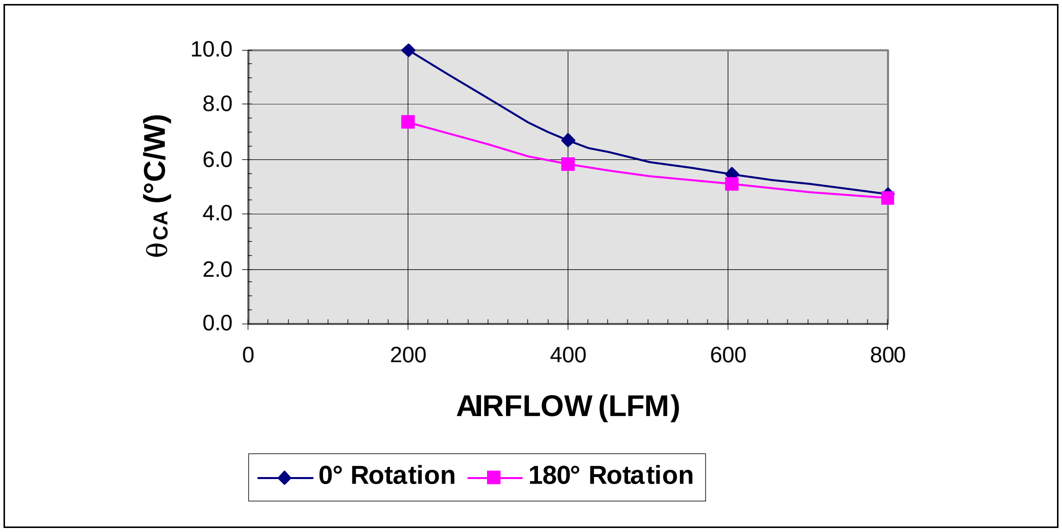


Table 6. Extruded Heat Sink: 82439HX System Controller (BGA) Thermal Resistance vs. Airflow

Airflow (LFM)	0° Rotation θ_{CA} (°C/W)	180° Rotation θ_{CA} (°C/W)
800	21.9	25.4
600	25.1	28.2
400	29.7	33.2
200	39.8	40.5

Figure 17. Extruded Heat Sink: 82439HX System Controller (BGA) Thermal Resistance vs. Airflow

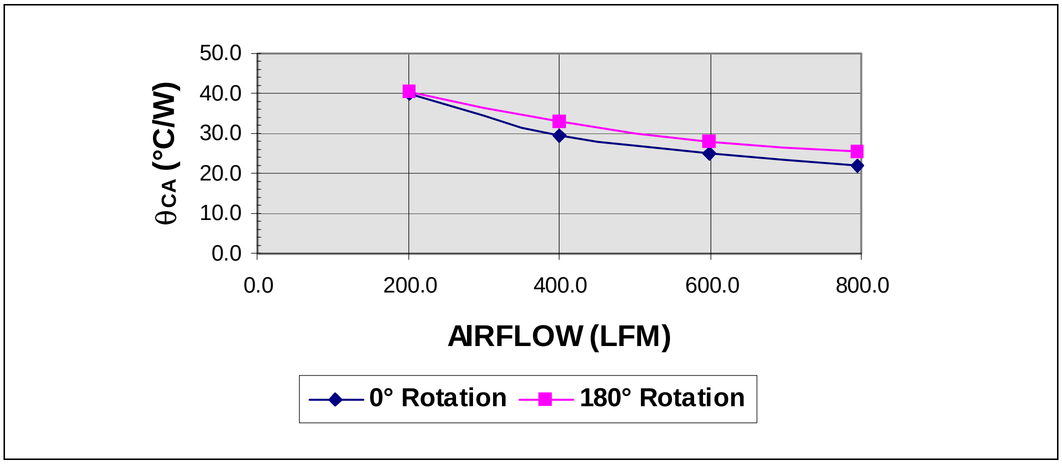


Table 7. Extruded Heat Sink: SRAM (TQFP) Thermal Resistance vs. Airflow

Airflow (LFM)	0° Rotation θ_{CA} (°C/W)	180° Rotation θ_{CA} (°C/W)
800	30.6	36.8
600	34.0	39.6
400	38.4	44.4
200	46.4	53.8

Figure 18. Extruded Heat Sink: SRAM (TQFP) Thermal Resistance vs. Airflow

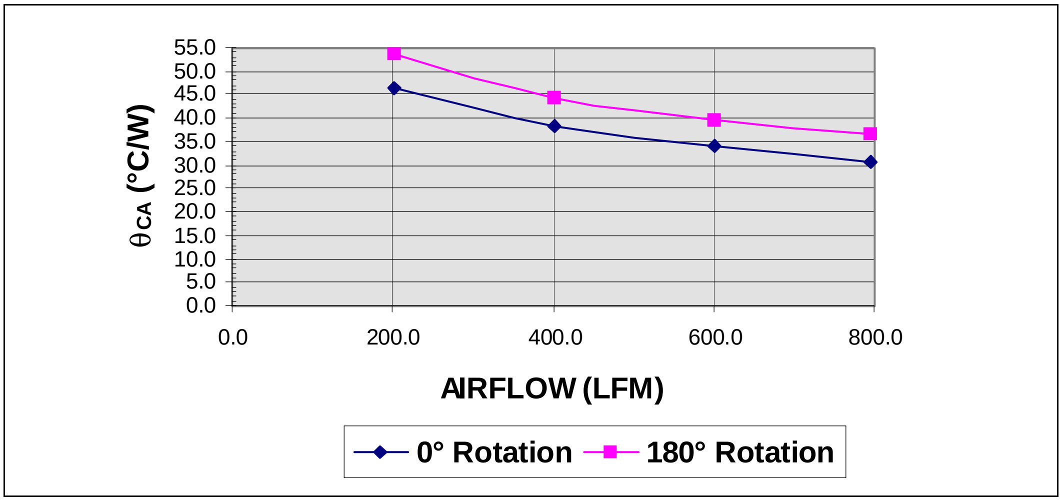


Table 8. Fan Heat Sink: 133 MHz Pentium® Processor (TCP) Thermal Resistance vs. Airflow

Airflow (LFM)	θ_{CA} (°C/W)
800	5.0
600	5.2
400	5.4
200	5.7
100	5.8

Figure 19. Fan Heat Sink: 133 MHz Pentium® Processor (TCP) Thermal Resistance vs. Airflow

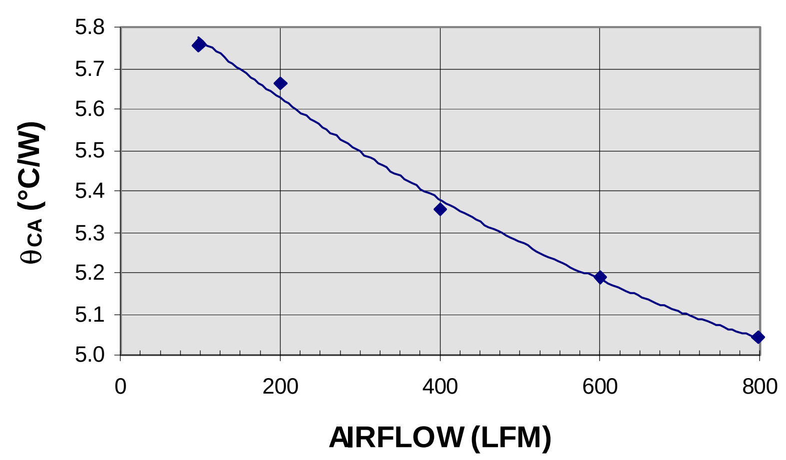


Table 9. Fan Heat Sink: 82439HX System Controller (BGA) Thermal Resistance vs. Airflow

Airflow (LFM)	θ_{CA} (°C/W)
800	21.5
600	23.9
400	28.0
200	32.1
100	34.5

Figure 20. Fan Heat Sink: 82439HX System Controller (BGA) Thermal Resistance vs. Airflow

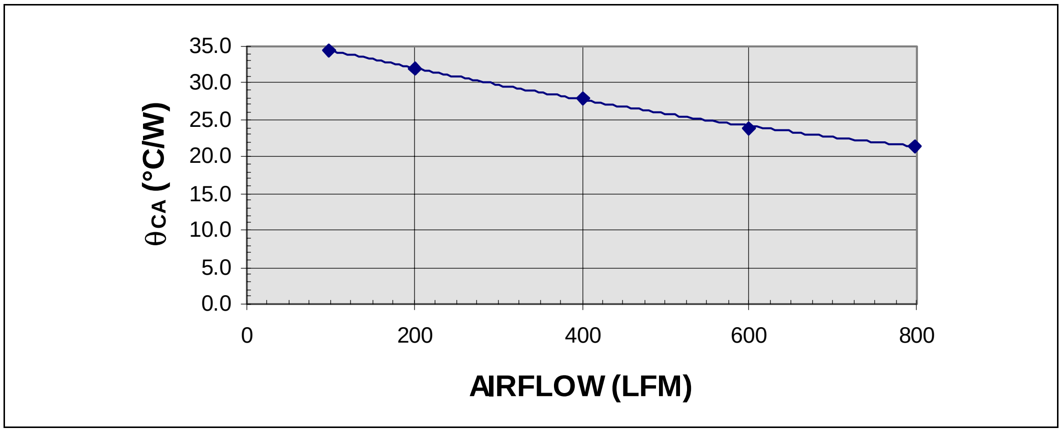
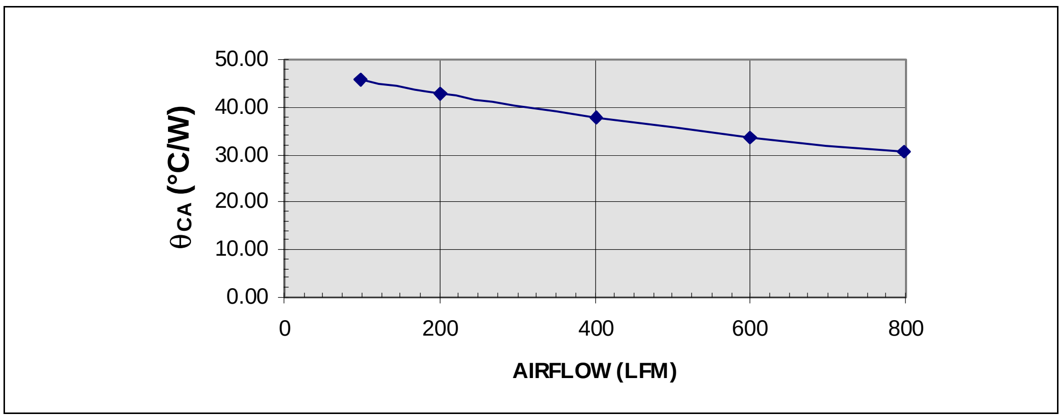


Table 10. Fan Heat Sink: SRAM (TQFP) Thermal Resistance vs. Airflow

Airflow (LFM)	θ_{CA} (°C/W)
800	30.9
600	33.6
400	37.9
200	42.9
100	45.9

Figure 21. Fan Heat Sink: SRAM (TQFP) Thermal Resistance vs. Airflow



7.9.4.2 EMBMOD166

Figures 22 and 23 and Tables 11 and 12 represent the data for the corrugated heat sink on the EMBMOD166 module.

Table 11. Corrugated Heat Sink: 166 MHz Pentium® Processor (TCP) Thermal Resistance vs. Airflow

Airflow (LFM)	0° Rotation θ_{CA} (°C/W)	180° Rotation θ_{CA} (°C/W)
800	4.6	4.8
600	5.2	5.3
400	6.6	6.1
200	9.7	7.9

Figure 22. Corrugated Heat Sink: 166 MHz Pentium® Processor (TCP) Thermal Resistance vs. Airflow

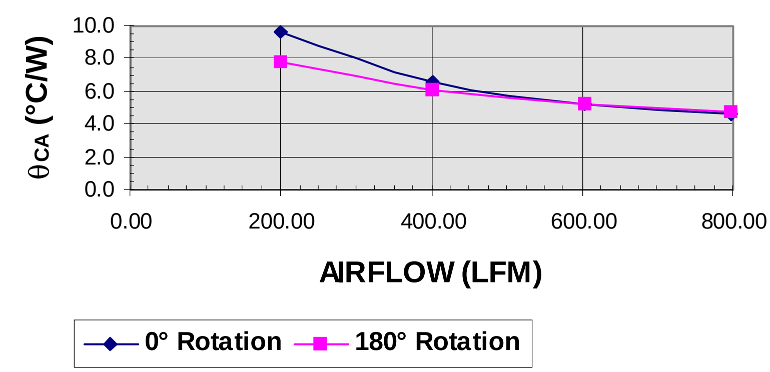
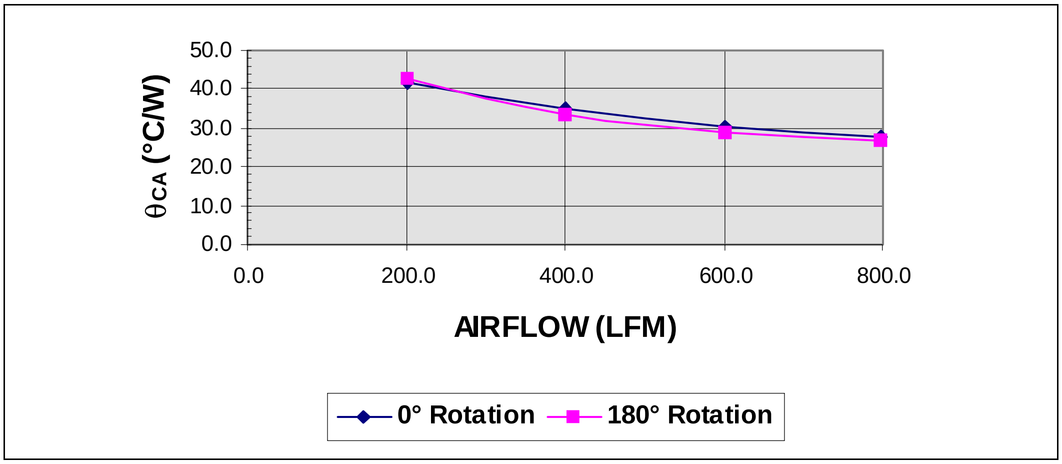


Table 12. Corrugated Heat Sink: 82439HX System Controller (BGA) Thermal Resistance vs. Airflow

Airflow (LFM)	0° Rotation θ_{CA} (°C/W)	180° Rotation θ_{CA} (°C/W)
800	27.8	26.7
600	30.5	28.8
400	34.9	33.6
200	41.7	42.7

Figure 23. Corrugated Heat Sink: 82439HX System Controller (BGA) Thermal Resistance vs. Airflow



8.0 Conclusion

As the complexity of the microprocessor increases so do the power dissipation requirements that affect board and system configuration. Care must be taken to ensure that heat resulting from the power is properly dissipated. The heat can be dissipated using passive heat sinks, fans and/or active cooling devices. The simplest and probably most cost-effective method is to use a heat sink or a fan heat sink. No matter which solution is chosen, maintaining the case temperature specification for each package is the only way to ensure proper functionality and reliability of the components on the Embedded Processor Module.

9.0 Related Documents

These documents are available for download from Intel's World Wide Web site at http://www.intel.com.

Table 13. Related Documents

Document	Order Number
Intel Embedded Processor Module datasheet	273105
Intel Embedded Processor Module Evaluation Board Developer's Manual	273122
AP-757, *Embedded Processor Module Design Guide*	273120
Intel Packaging Handbook	240800
Pentium® Processor with Voltage Reduction Technology datasheet	242557
Mobile Pentium® Processor with MMX™ Technology datasheet	243292

Appendix A Vendor List

This vendor list is provided as a service to our customers for reference only. The inclusion of this list should not be considered a recommendation or product endorsement by Intel Corporation.

Table 14. Vendor List (Sheet 1 of 2)

Heat Sink Vendors	
Aavid Thermal Products, Inc. One Kool Path PO Box 400 Laconia, NH 03247 Phone: 603-528-3400 Fax: 603-525-1478 Part Number: NP970255	**SMI Electronic Devices America, Inc.** 4645 S. Lakeshore Drive Suite # 11 Tempe, AZ 85282 Phone: 602-820-9889 Part Number: 29990-071
Fan Heat Sink Vendors†	
North America: **Sourceline, Inc. (Panasonic)** 122 Charcot Ave. San Jose, CA 95131 USA Phone: 800-891-0649 Fax: 408-727-3350 Part Number: UDQFNAE02F	*Japan*: **Kyushu Matsushita Electric** 2111 UEDA OITA, 879-04 Japan Phone: (0978)37-1991 Fax: (0978)37-3502 Part Number: UDQFNAE02F
Heat Pipe and Heat Exchanger Vendors	
Fujikura America, Inc. 3001 Oakmead Village Drive Santa Clara, CA 95051 Phone: 408-988-7408 or 408-988-7415 Fax: 408-727-3515	**Thermacore, Inc.** 780 Eden Road Lancaster, PA 17601 Phone: 717-569-6551 Fax: 717-569-4797
Interface Material Vendors	
MicroSi 1028 S 51st St. Phoenix, AZ 85044 Phone: 602-893-8898 Fax: 602-893-8637 Part Number: X-23-7654	**The Bergquist Company** 5300 Edina Industrial Blvd. Edina, MN 55439 Phone: 612-835-2322 Fax: 612-835-4156
Air Velocity Meter Supplier	
Kurz Instruments, Inc. 2411 Garden Road Monterey, CA 93940 Phone: 800-424-7356 Part Number: 753070 Series 490-IS	

† For all other areas, please contact your local Panasonic Sales Office.

Table 14. Vendor List (Sheet 2 of 2)

Copper Heat Spreader Supplier	
Chomerics 77 Dragon Court Woburn, MA 01888-4014 Phone: 617-935-4850 Fax: 617-933-4318	
Board Manufacturer	
Avex Electronics Inc. 4807 Bradford Drive Huntsville, AL 35805 Phone: 205-722-6000	
CompactPCI Specification	
Rogers Communication 301 Edgewater Place, Suite 220 Wakefield, MA 01880 Phone: 617-224-1100 Fax: 617-224-1239	
Temperature Measurement Suppliers	
Omega Engineering, Inc. One Omega Drive P.O. Box 4047 Stamford, CT 06906 Phone: 1-800-622-2378	
Spring Suppliers	
Associated Spring Raymond 1705 Indian Wood Circle Suite #210 Maumee, OH 43537-9843 Phone: 800-872-7732 Part Number: C0180-018-0250	**Kato Spring of California, Inc. Eastern Operations** 1200 Northbrook Parkway, Suite 160, Suwanee, GA 30024, U.S.A. Phone: 770-682-2600 Fax: 770-682-2610 Part Number: IASK9801 OKU-A0.25
TUFLOK* Pin Supplier	
Manufacturer: **ITW Fastex** 195 Algonquin Road Des Plaines, IL 60016 Phone: 847-299-2222 Fax: 847-390-8727 Part Number: 3170-00-2099	*Distributor:* **Pencom** 1300 Pioneer St., Suite E Brea, CA 92821 Phone: 562-694-4477 Fax: 562-694-8840 Part Number: 3170-00-2099
Thermal Transfer Plate Vendors	
Thermalloy, Inc. 2021 W. Valley View Lane Dallas, TX 75234-8993 Phone: 972-243-4321 Fax: 972-241-4656	**Aavid Thermal Products, Inc.** One Kool Path PO Box 400 Laconia, NH 03247 Phone: 603-528-3400 Fax: 603-525-1478 Part Number: NP970255

† For all other areas, please contact your local Panasonic Sales Office.